CONTINUOUS VACUUM DRYING OF WHOLE MILK FOAM 2442
II. MODIFIED PROCEDURE

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ABSTRACT

A modified procedure is described whereby heat and mass transfer are improved in the continuous vacuum foam drying of whole milk. It results in superior products largely as a consequence of lower heat damage and shorter drying times. The technique involves controlling the degree of subsidence of a foam film during drying by manipulating process variables, particularly the vacuum in the drying chamber.

Two major problems encountered during the development of controlled foam subsidence were rehydration of the dried foam due to high humidity conditions during the latter drying stages—now overcome—and the variable seasonal foaming properties of milk—yet to be solved. The modified procedure yields products of excellent flavor and dispersibility at rates which, if obtained year-round commercially, would permit the profitable sale at less per reconstituted quart than fluid milk in the store. Currently, work is being directed toward overcoming the seasonal variability problem and maximizing of the product rate while maintaining product quality.

A broad research program directed toward developing an economically feasible process for beverage-quality dry whole milk of easy dispersibility and adequate shelf-life is in progress in the Engineering and Development Laboratory of the Eastern Utilization Research and Development Division. The principles developed on a batch scale for preparing vacuum foam-dried whole milk (9) have been successfully applied on a continuous basis (2). In the latter work, conditions studied were restricted to those found to preserve foam integrity during drying, as in the case of the batch process. Unfortunately, this results in thick, slow-drying films poorly bonded to the drying belt, with consequent low production rates. Thus, modification of process operation to improve heat and mass transfer during drying, while maintaining product quality, was indicated. This paper reports on the development of a procedure for obtaining thin films of foam uniformly distributed and well-bonded to the belt; the impact on product quality and costs; and the problems encountered in exploiting the modified procedure.

In the continuous process a film of milk concentrate foam is continuously applied to and dried on a moving, solid stainless steel belt housed in a vacuum chamber. The foams are formed when an inert gas, previously entrained in the chilled concentrate feed, is expanded as the feed is pumped into the vacuum chamber through a nozzle. Initial formation of the foam takes place in a small space behind the nozzle slot, through which a ribbon of foam is extruded on to the belt. Heat is radiated to the foam and to the underside of the belt directly after the foam leaves the nozzle. The temperature of the foamed concentrate quickly approaches its boiling point, determined by the absolute chamber pressure, and drying commences. Further expansion of the foam also occurs here. The structure produced in this short but critical zone influences the rate of drying and ultimate product quality. For instance, when the conditions are such that the foam, as produced in this zone, is fully maintained, thick, poorly bonded, slow-drying films result. Figure 1 shows the foam emerging from the nozzle and expanding after entering the heated zone. Figure 2 shows the final foam structure which has emerged from the critical zone.

To alter this undesirable foam structure, attention was turned to those controllable process variables likely to affect foam behavior in the critical zone. After a careful study of concentrate viscosity and gas content, nozzle aperture, foam temperature (established by pressure in drying chamber), and rate of heat application, it soon became apparent that most of the desirable changes in foam behavior could be achieved by increasing chamber pressure. A systematic study showed that milk foams can be made to subside

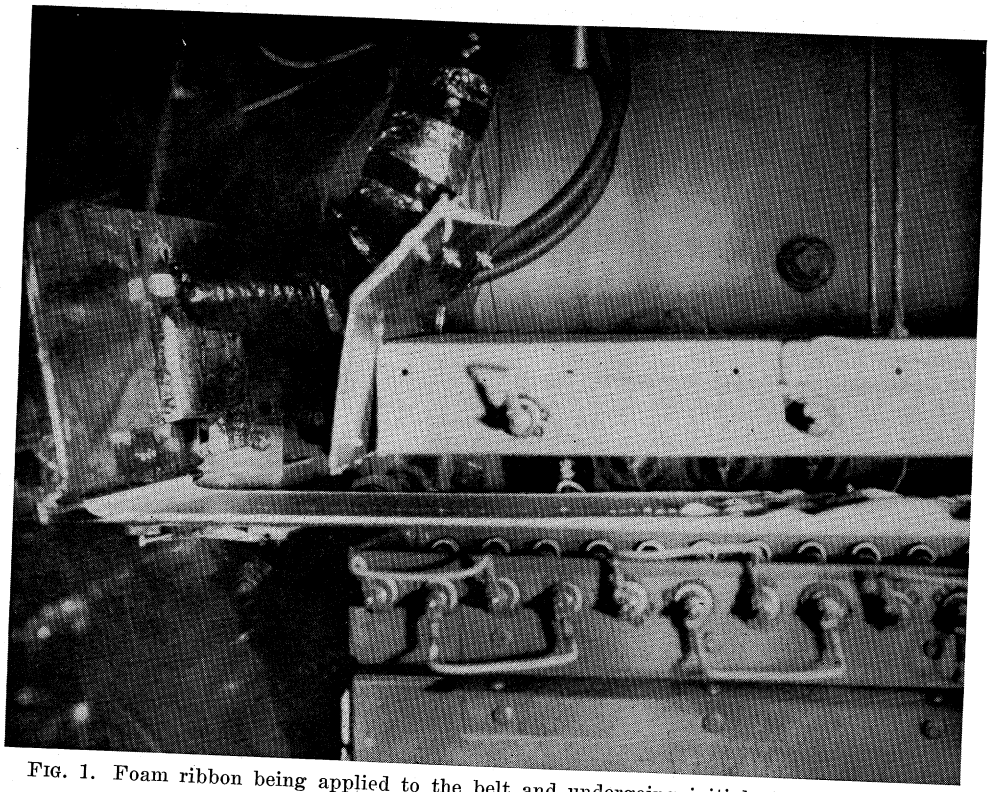

FIG. 1. Foam ribbon being applied to the belt and undergoing initial stages of drying.

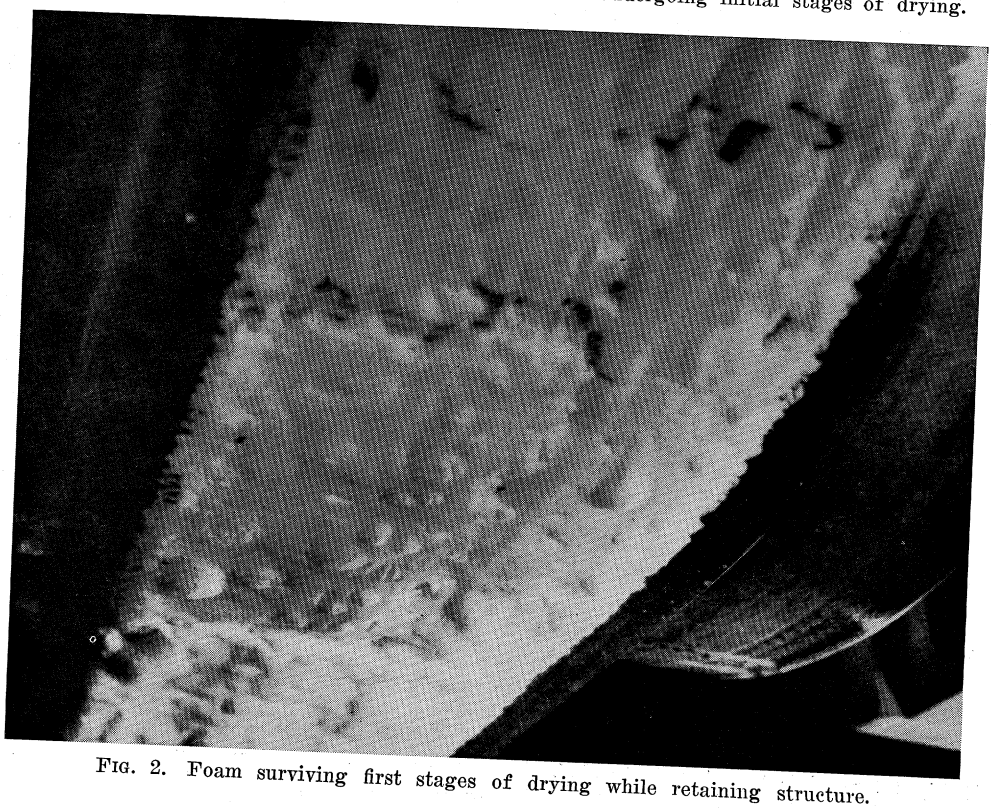

FIG. 2. Foam surviving first stages of drying while retaining structure.

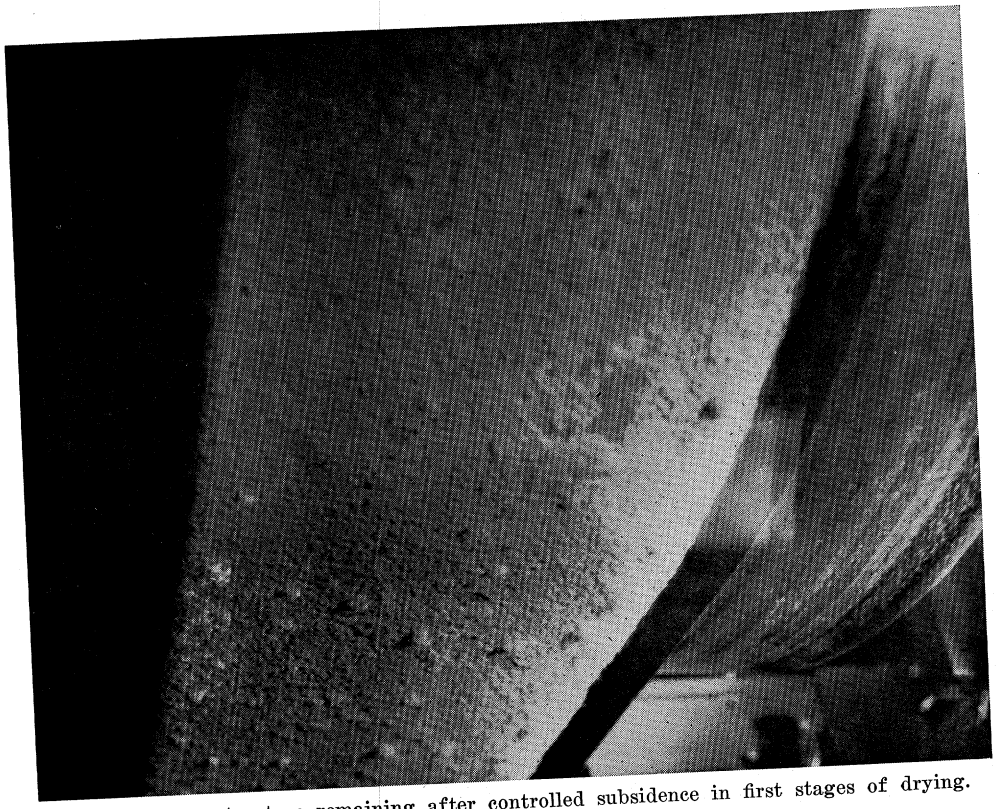

FIG. 3. Foam structure remaining after controlled subsidence in first stages of drying.

to varying degrees by manipulating dryer chamber pressure over a range 9-22 mm Hg abs. At about 18 mm (corresponding to a foam temperature of about 24 C) the foam subsides to a thin film, well-bonded to the belt, and dries rapidly. The resulting foam structure represents a residual expansion of about 20-25-fold with respect to ungassed concentrate. This is in contrast to the 75-100-fold expansion obtained when the foam does not subside. Figure 3 depicts this more desirable final foam structure as it passes over the steam-heated drum.

It is of interest to note that the desirable drying temperature falls within the range of 20 to 30 C where fluid milk is reported to have a minimal tendency to foam (4, 8). Foaming increases rapidly above and below this temperature range. Other investigators (5) found for solutions of milk proteins a minimum in half-volume time (the time for a foam to subside half-way) at about 21 C. Work at this Laboratory (7) on milk concentrate foams showed a similar effect of temperature.

OPERATIONAL PROBLEMS

Although operation of the dryer at about 18 mm Hg abs is superior in some respects, two major problems have been encountered at this higher pressure. One was revealed only after sampling devices were developed and installed at critical points in the dehydrator. Figure 4 shows locations *(S)* of the sampling apparatus at the end of each of three major drying zones. These permit removal of representative samples from the moving belt while at steady-state conditions, without significant disruption of operation.

Moisture content of samples taken at the

SCHEMATIC DRAWING OF THE CONTINUOUS VACUUM DRYER

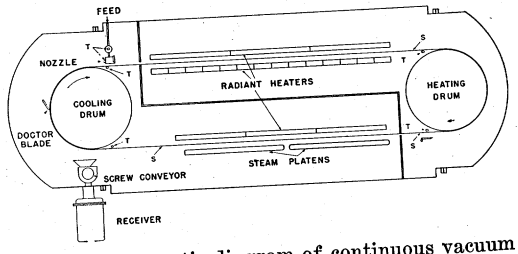

FIG. 4. Schematic diagram of continuous vacuum foam belt dryer depicting partition (heavy line), position of samplers *(S)*, and position of thermocouples *(T)*.

location just before the cold drum, compared to that of corresponding products collected in the receiver, revealed rehydration as high as a 2 to 2½% moisture increase (e.g., a 3% product may rehydrate to 5.5%). Moreover, under some conditions, moisture content of a sample taken at the location just after the hot drum was lower than the moisture content of sample from the receiver. Thus, the drying that took place after the hot drum was completely vitiated. This rehydration is a consequence of the higher chamber pressures employed. In this tight vacuum drying system the water vapor pressure is almost equal to the total pressure and exceeds the equilibrium moisture of the dry milk, resulting in rehydration. Also, since the belt and consequently the product is cooled to below the condensation temperature on the cooling drum, another means for increasing moisture is afforded. Solution of the rehydration problem was achieved by constructing a partition between the wet and dry dryer zones, as indicated by the heavy line in Figure 4. In the upper right half of the dryer more than 90% of the moisture is removed and it has ready access to the vacuum line. In addition, the cold drum, which operates at about 0 C and performs as an effective condenser, has been isolated from the wet section. Admitting small quantities of dry gas into the lower left section assures maintenance of a low dewpoint in this region where low product moistures exist. With this arrangement rehydration is now insignificant.

The other major problem is not so easily solved. The work leading to the development of the new procedure was done in what we have come to refer to as the winter season. As the work progressed through the spring and summer seasons the foam could no longer be made to subside as much as in the winter season and thick, slow-drying foams, reminiscent of low-pressure operation, resulted. Moreover, a thorough study of those variables known to affect foam behavior offered no solution to the summer-milk problem. It was apparent, then, that milk produced during the winter season has foam properties different from those observed in summer milk. Work in this Laboratory (7), with pooled milk from the Philadelphia milk shed, has shown a major factor responsible for these changing foaming properties of milk to be naturally occurring variations in the concentration of phospholipids. Lecithin enrichment offers a potential for solving this problem.

PRESENT STATUS OF THE PROCESS

Research on the continuous process for vacuum drying whole milk foams first reported in 1962 (2) has led to the following advances:

Thin, fast-drying films, formed by the techniques describes here, give in the pilot plant products of excellent flavor and desirable physical characteristics at rates which, if obtained year-round commercially, would permit the profitable sale at less per reconstituted quart than fluid milk in the stores (10). This is a consequence both of increased dryer output and greatly increased (from 0.22 to 0.40 g/cc) product densities. The excellent product quality is largely a consequence of shortened drying times and lower over-all heat exposure, as evidenced by the quantity of 5-hydroxymethylfurfural (HMF) formed (3). Dispersibility remains unimpaired after 1 yr at room temperature. Other work in this Laboratory (1) showed that flavor is well-retained under ordinary refrigeration for at least nine months, but is limited to a few weeks at room temperature. Since processing and packaging are done in an air-free atmosphere, the objectionable flavors caused by oxidative deterioration have been substantially eliminated.

Currently, work is directed to two objectives. The first is a seasonal control of the foaming characteristics through use of lecithin addition and adjustment of process variables. The second is optimization of the process for the 13 known independent variables (which include factors describing the feed to the dryer and drying conditions) and six dependent variables (which include production rate along with chemical and physical attributes of the product).

ACKNOWLEDGMENTS

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